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(71) Applicant *(for all designated States except US)*: **UNIVERSITY OF LEEDS** [GB/GB]; 175 Woodhouse Lane, Leeds, West Yorkshire LS2 9JT (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **Appleyard, Steven, Philips** [GB/GB]; 4 Carr Lane, Rawdon, Leeds LS19 6PF (GB). **LU, Shilin** [CN/GB]; 6 Walkers Mount, Leeds LS6 2SD (GB). **RAND, Brian** [GB/GB]; 38 Housley Park, Chapeltown, Sheffield S35 2UE (GB).

(74) Agents: **STUTTARD, Garry, Philip** et al.; Urquhart-Dykes & Lord, Tower House, Merrion Way, Leeds LS2 8PA (GB).

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(54) Title: HIGHLY ORIENTED MESOPHASE PITCH-BASED GRAPHITE TAPE AND BULK CARBON MATERIAL

(57) Abstract: A method for producing highly oriented mesophase pitch-based tapes and for producing highly oriented bulk carton materials from the highly oriented mesophase pitch-based tapes in which mesophase pitch is extruded through a die with an aspect ratio greater than 10.

HIGHLY ORIENTED MESOPHASE PITCH-BASED GRAPHITE TAPE AND BULK CARBON MATERIAL

The present invention relates to a method for producing highly oriented mesophase pitch-based tapes and to a method for producing highly oriented bulk carbon materials from the highly oriented mesophase pitch-based tapes, and to the tapes and the bulk carbon materials *per se* and to composite materials that contain continuous or discontinuous tapes.

The graphite crystal is rendered highly anisotropic by its structure which is composed of stacks of sheet-like layers of carbon atoms (graphene layers). In the plane of the sheets, the carbon atoms are covalently bonded by sp^2 hybridisation of the electron orbitals. These layer planes are weakly held together by weak Van Der Waals-type forces. Theoretically graphite has exceptionally high elastic modulus (1060GPa) and it also displays extremely high thermal conductivity along the basal plane (significantly higher than that of most conductive metals such as copper and silver, even higher in specific terms). It follows that in an article made of perfectly aligned graphene planes, the material would have extremely high tensile elastic modulus in the basal plane directions since the load would be opposed by the covalent bonds themselves.

There are no artificial bulk carbon and graphite materials available with properties equivalent to those of the graphite crystal. However, there are carbon and graphite materials which have realised a fraction of these properties. An extremely wide range of properties may be engineered in carbon materials which may be produced from a variety of precursors through different processing routes.

Carbon materials are widely used and play an essential role in aerospace, nuclear, metallurgical, chemical, mechanical and electrical applications.

Bulk carbon and graphite materials (such as electrodes used for steel making and anodes for the aluminium industry) are produced from carbonaceous filler particles (cokes, graphite or carbon black) combined with a pitch binder. The raw materials are mixed to ensure even distribution of the binder and then formed by extrusion or moulding. The bulk product is calcined and the pitch binder decomposes to carbon. A high temperature of >2500°C is required to convert the carbon to graphite. At this stage the graphite bulk density is of the order of ~1.7 Mgm^{-3} with a porosity in the region of ~25%. Thus the fabrication process usually requires lengthy, multiple pitch impregnation and pyrolysis cycles to reduce the porosity.

The properties of the filler coke particles and pitch binder as well as the processing conditions strongly influence the properties of the final bulk graphite artefacts. Coke particles may show preferred orientation along the extrusion direction which is particularly true if anisotropic or "needle" cokes are used giving an electrode with anisotropic properties. The properties of carbon and graphite materials produced in this way are complicated by the anisotropic nature of the crystallites but (generally speaking) they are porous and of low strength. The bulk anisotropic properties are dependent on the size and arrangement of crystallites within the structure.

The cokes used in this process are often produced from petroleum pitches. During pyrolysis most pitches pass

through a discotic nematic liquid crystal phase when the polyaromatic molecules align in domains. This is an essential stage in the formation of graphitising carbon from such precursors. It is known as the carbonaceous mesophase and has been exploited to produce advanced carbon and graphite fibres and composites.

Carbonaceous mesophase may be formed in complex polycyclic aromatic hydrocarbon mixtures such as petroleum or coal tar pitches when heated within the temperature range 350-500°C [Brooks *et al* (1965). Carbon 3, p 185]. In the early stages of the transformation, mesophase precipitates from the pyrolysing matrix as small spheres. According to the Brooks-Taylor model, within the central region the mesophase layers lie parallel to define the polar diameter but curve to meet the interface with the pitch matrix at a high angle. As pyrolysis proceeds, these mesophase spheres grow and coalesce to larger spheres. Coalesced mesophase spheres show more complicated extinction patterns than the spheres which first appear (see Figure 1). As pyrolysis continues, the coalescence proceeds and eventually the material becomes entirely or substantially converted to the mesophase state.

Certain mesophase pitches can be formed into fibres through melt spinning. The mesophase pitch melt is usually extruded through a multiple-hole spinneret. The extrudates are draw down as they cool and eventually solidify to form the fibres. When molten mesophase pitch is forced through the spinneret, the planar polyaromatic molecules are lined up in the flow direction. The alignment is further improved during the fibre drawdown. Hence, the polyaromatic molecules are aligned more or less parallel to the fibre axis in the "as-spun" fibres and thereby producing fibres with

exceptional stiffness after carbonisation and graphitisation. For a given pitch, the spinning conditions have a strong impact on the degree of preferred orientation of "as-spun" fibres which is higher when the spinning viscosity is low. It has been suggested that mesophase pitch-based fibres of larger diameter produced from lower viscosity precursors have a higher degree of preferred orientation. The fibres of smaller diameter cool more rapidly during the elongation process thereby inheriting a lower degree of preferred orientation as disordered states at higher temperature are locked in.

In order to retain the fibre shape and the preferred orientation of mesophase molecules induced during spinning, "as-spun" fibres must be stabilised to render them infusible before further heat treatment. Stabilisation is normally achieved through oxidation in which the "as-spun" fibres are heated in an oxygen-containing atmosphere to temperatures between 200 and 350°C for a period of time sufficient to prevent fibres deforming and/or sticking during carbonisation. The stabilisation step can have a significant impact on the microstructure as well as the mechanical strength of the finished fibres. Two kinds of chemical reactions take place simultaneously during stabilisation. The first is oxygen uptake into the fibre constituents and the second is the evolution of volatile organic vapours and oxygen-containing gases. The weight gain is rapid in the early stages of oxidation but decreases with prolonged exposure. The amount of oxygen uptake is critical. It must be adequate to preclude interfusion of fibres yet low enough not to disrupt the fibre structure when it is eventually expelled as CO and CO_2 during carbonisation. An oxygen uptake of 6 to 7 wt% is known to be adequate for

stabilisation. The oxygen absorbed by the fibre forms oxygen-containing functional groups that may cross-link and preserve the axial preferred orientation of the fibre during carbonisation and reduce the solubility of the fibre constituents.

Stabilised pitch fibres are infusible. They have poor mechanical properties, are fragile and difficult to handle. Carbonisation of the stabilised fibres is required to convert the molecular solid into a paracrystalline carbon state. Graphitisation at temperatures above 2000°C is a further option and is known to confer exceptional properties. Graphitisation involves the development of graphitic order in the fibres. The highly oriented structure of the "as-spun" fibres is enhanced in the carbonised state provided that they have been sufficiently well oxidised prior to carbonisation. Increasing the final heat treatment temperature brings about an increase in crystallite size and perfection and in the degree of preferred orientation of layer planes along the fibre axis thereby resulting in an improvement in mechanical and other properties.

The mechanical properties of pitch-based carbon fibres produced by BP-Amoco are listed in Table 1 [BP-Amoco data sheet]. In the extreme cases, these mesophase pitch-based carbon fibres may display a high modulus which is very close to the theoretical value of single crystalline graphite.

Table 1. Properties of some highly oriented BP-Amoco pitch-based carbon fibres

Fibres	Diameter μm	Tensile strength GPa	Young's modulus GPa	Elongation to failure %	Density Mgm^{-3}	Thermal Conductivity $Wm^{-1}k^{-1}$
P120s	10	2.41	827	0.3	2.17	640
K1100	10	3.10	965	-	2.20	900-1000

Carbon fibres may have excellent mechanical and transport properties but only in one direction. For effective use in composites they are combined in woven structures to give two, three and multi-directional properties. The formation of complete woven structures is an additional cost in the production of high performance composites.

The need for materials capable of withstanding the tremendous thermal erosion and thermal shock experienced by spacecraft and rockets has led directly to the development of carbon-carbon composites. A carbon-carbon composite is a carbon fibre-reinforced carbon matrix material. Carbon fibres are produced from a variety of precursors including pitch, polyacrylonitrile (PAN), rayon and organic vapours. The carbon matrix phase is typically formed by solid, liquid, or gaseous-phase pyrolysis of an organic precursor material. Carbon-carbon composites seek to combine the high strength, stiffness and toughness of carbon fibre with the excellent thermomechanical properties of bulk polygranular carbons. There are two main methods of formation of the carbon matrix, namely (1) chemical vapour deposition from a hydrocarbon gas (CVD) or (2) carbonisation of a carbonaceous resin or pitch.

The variety of structures displayed by carbon fibres and carbon matrices give the composite a broad range of

properties (mechanical and physical). In addition, the interaction between the carbon fibres and the matrix carbons plays an important role in determining the properties of the composite. Properties of carbon-carbon composites that make them attractive substitutes for other structural materials (such as metals and alloys) include high specific strength and stiffness, high temperature strength, high corrosion resistance, low thermal expansion, good friction and wear properties and high thermal and electrical conductivity. The use of these high performance materials has been developed in areas as diverse as integrated rocket throat nozzles, nosecones, aircraft brakes, structural materials in the aerospace industry, molten glass handling and biomedical implants.

The very high thermal conductivity of mesophase pitch-based carbon fibres is due to a highly oriented graphite crystalline structure along the fibre axis. The thermal conductivity of the mesophase pitch-based carbon fibre Thornel K-1100 is 900-1000$Wm^{-1}K^{-1}$ which is more than twice that of copper or 10 times in specific terms. One high profile application of mesophase pitch-based carbon fibre reinforced composites is their use as thermal management materials such as satellite radiators and electronic packagings. Perceived new widespread applications such as heat sinks leads to a need for improved materials and new production methods.

As mentioned hereinbefore, the low mechanical and poor transport properties of polygranular materials are attributable to the high porosity and almost random orientation of the crystallites. An approach that reduces porosity is the method of producing so-called "sintered"

carbons, although the random orientation of crystallites still pervades.

Sintered carbons can be made by grinding a mesophase pitch into particles, forming the ground particles into desired shape and finally heating the shaped article to carbonise it. This ground mesophase has to be stabilised to a certain degree or otherwise treated to control its thermoplasticity; too little thermoplasticity and the powder becomes undeformable and yields low green densities, too much thermoplasticity and the powder becomes too fluid and 'bloats'. The intrinsic density of the powder increases progressively with heat treatment through to graphitisation temperatures. The particle shrinkage is due to the decrease in its inter-basal plane spacing (d_{002}) which approaches that of graphite crystal. Thus to produce high-density, high strength carbons the shrinkage of the bulk material must be matched by the shrinkage of the particles to avoid the formation of pores. Although high strength high-density bulk materials can be produced, they still have isotropic properties due to a lack of preferred orientation of the crystallites.

Similar to the production of sintered carbon, highly oriented bulk carbon materials can be produced by pressing mesophase pitch-based fibres. This has been adopted in the so-called self-reinforcing method by pressing the as-spun mesophase pitch fibres into panels before thermosetting and further heat treatment [Barr *et al*, 22th Biennial Conf. on Carbon, 1995, p.32]. BP-Amoco Performance Products Inc. recently developed a family of self-reinforced panels (ThermalGraph^R) from as-spun mesophase pitch fibres (average diameter ~10μm). The high thermal conductivity of mesophase

pitch-based carbon fibres is attributable to the extended graphitic crystalline structure oriented along the fibre axis. However the extension of the graphitic layer structures normal to the fibre axis is constrained by the geometric size of the fibres. Interfibre porosity is present in ThermalGraph^{R}. A further disadvantage is that the high thermal conductivity can only be achieved in one direction due to the unidirectional orientation of the fibrous components. Bidirectional properties are difficult to achieve by simply aligning the fibres in two directions because of the circular geometry of the fibres.

Mesophase pitch-based carbon fibres may have different transverse textures which are evident under a scanning electron microscope. Schematic drawings of the transverse textures commonly found in circular mesophase pitch-based carbon fibres are shown in Figure 2. The radial structure is the most commonly found transverse texture. It is believed that the transverse texture is "set in" during the extrusion of mesophase pitch through the spinneret and is preserved by stabilisation. There have been many attempts to produce noncircular fibres such as C-shaped, trilobal and rectangular ribbons. The desire to produce non-circular carbon fibres is driven by the readiness for stabilisation of such fibres (compared with round fibres with equivalent cross-sectional area) because non-circular fibres can have shorter oxygen diffusion distance from the surface. In addition, they tend to have better mechanical properties. However, cross-sectional areas of these fibres are still relatively small and the subject has been hindered by an insufficient understanding of microstructural control and numerous technical problems [Edie *et al*, *Carbon*, 1994, **32**, 1045; Edie *et al*, *Carbon*, 1993, **31**, 941; Robinson *et al*,

Carbon, 1996, **34**, 13; Edie *et al*, *High Temperatures-High Pressures*, 1990, **22**, 289; Mochida *et al*, *J. Mater. Sci.*, 1993, **28**, 2331; and Stoner *et al*, *High Temperatures-High Pressures*, 1990, **22**, 299].

Ribbon fibres can be beneficial for making a bidirectional arrangement and are suitable for thermal management applications due to their structure which has high thermal conductivity compared with circular fibres. However known ribbon fibres have small transverse areas and the layer structures which allow graphite growth are constrained. Ribbon fibres developed by Edie *et al* and Mochida *et al* (supra) have small cross-sectional areas. Although different transverse textures are known for circular mesophase pitch-based carbon fibres (radial, onion-skin, flat-layer, radial-folded and random - see Figure 2), only line-origin texture has been reported for ribbon fibres. Edie *et al* used slot dies to produce ribbon fibres (see Figure 2). The largest aspect ratio adopted was 9.

The present invention is based on the recognition that when the aspect ratio of the die slot is increased above conventional levels, the molecular orientation in the extruded and drawn tape undergoes a transition that is a function of shear rate. The invention represents an efficient method for producing carbon materials for *inter alia* thermal management applications and potentially has enormous commercial value.

Thus viewed from one aspect the present invention provides a method for preparing mesophase pitch-based tape comprising: extruding mesophase pitch through a slot shaped die (*eg* a

rectangular die) with an aspect ratio of 10 or more and drawing at a draw ratio greater than 5.

The method of the invention permits preparation of wider tapes (or sheets) having enhanced properties in directions parallel to the plane and over a wider area. Conventional fibre structures may be replaced with tapes (or sheets) of the invention in the manufacture of polymer matrix composites or carbon matrix composites or metal matrix composites.

In a preferred embodiment of the method of the invention, the mesophase pitch-based tape is subjected to an elevated temperature. For example, the mesophase pitch-based tape may be carbonised to carbon tape or graphitised to graphite tape.

Preferably the mesophase pitch-based tape is stabilised in a stabilisation step (*eg* oxidatively stabilised). Particularly preferably, stabilisation is followed by heat treatment at an elevated temperature (*eg* at a temperature above 400°C).

Preferably the aspect ratio of the die is 20 or more, particularly preferably 30 or more, more preferably 40 or more, more especially preferably about 50 or more, even more especially preferably 60 or more, yet even more especially preferably 70 or more (*eg* about 80).

By carefully controlling the shear rate and draw ratio, mesophase pitch-based tape may be produced in which the planar molecules predominantly arrange either parallel to the major tape surface or perpendicular to the major tape surface. For a die of aspect ratio greater than 10, a lower

shear rate is generally required to produce a tape in which the planar molecules arrange mainly parallel to the major tape surface. Conversely, a higher shear-rate in the die is generally required to produce a tape in which the planar molecules arrange mainly perpendicular to the major tape surface.

The term shear rate as used herein is defined as:

$$\text{Shear rate at the wall} = (4Q)/(\pi r^3)$$

(where Q is the volumetric flow rate and r is the hydraulic radius which for a slot-shaped die = 2(area)/perimeter).

Typically the shear rate in the die is in the range 1700 to $33000s^{-1}$. Preferably the shear rate in the die is in the range 1700 to $5000s^{-1}$. Preferably the shear rate in the die is in the range 5000 to $33000s^{-1}$.

For example, for a given mesophase pitch (*eg* ARA 24) using a die of aspect ratio 50, a tape in which the planar molecules arrange mainly parallel to the major tape surface may be produced using a shear rate in the range 1900 to $4000s^{-1}$ (for example $1961s^{-1}$, $2017s^{-1}$, $2178s^{-1}$, $2338s^{-1}$, $2599s^{-1}$, $2684s^{-1}$, $3150s^{-1}$, $3273s^{-1}$, $3363s^{-1}$ or $3830s^{-1}$). For the same mesophase pitch using a die of aspect ratio 50, a tape in which the planar molecules arrange mainly perpendicular to the major tape surface may be produced using a shear rate in the range 5400 to $11100s^{-1}$ (for example $5405s^{-1}$, $5463s^{-1}$, $8053s^{-1}$, $8828s^{-1}$, $8881s^{-1}$, $9126s^{-1}$, $9864s^{-1}$, $10953s^{-1}$, $11084s^{-1}$ or $32921s^{-1}$). For the same mesophase pitch using a die of aspect ratio 80, a tape in which the planar molecules arrange mainly parallel to the major tape surface may be produced using a shear rate

in the range 1700 to 4900s^{-1} (for example 1758s^{-1}, 2688s^{-1}, 3189s^{-1} or 4828s^{-1}). For the same mesophase pitch, using a die of aspect ratio 80, a tape in which the planar molecules arrange mainly perpendicular to the major tape surface may be produced using a shear rate in the range 6600 to 12600s^{-1} (for example 6617s^{-1}, 6991s^{-1} or 12585s^{-1}).

By way of example, a die with an aspect ratio of 50 has been used to produce highly oriented continuous mesophase pitch-based tapes which have novel flat-layer transverse texture and a cross-sectional area about 100 times greater than conventional mesophase pitch-based carbon fibres. In addition, the tape maintains excellent mechanical properties. The tensile strength of the carbonised mesophase pitch-based tape with a cross-sectional area of 5000$(\mu m)^2$ is of the order of 1GPa. This transverse area is equivalent to that of a circular fibre with a diameter of 80μm. Such a circular fibre would take several days to stabilise and once carbonised would only have a tensile strength of the order of 0.2GPa due to the presence of defects. The electrical resistivity of 2700°C heat-treated mesophase pitch-based tape with cross-sectional area ~8000$(\mu m)^2$ is ~1.2$\mu\Omega m$. This is equivalent to that of the most thermally conductive known mesophase pitch-based carbon fibres K1100 which have been heat treated to >3000°C. This suggests that the novel mesophase pitch-based tape of the invention may have lower electrical resistivity when heat-treated to >3000°C. The measured electrical resistivity indicates that high thermal conductivity is expected in accordance with Lavin *et al*, *Carbon*, 1993, **31**, 1001 (see Figure 3).

Viewed from a further aspect the present invention provides a mesophase pitch-based tape (or sheet) obtainable by

extruding mesophase pitch through a slot-shaped die with an aspect ratio of 10 or more, preferably 20 or more, particularly preferably 30 or more, more preferably 40 or more, more especially preferably about 50 or more, even more especially preferably 60 or more, yet even more especially preferably 70 or more (*eg* about 80). The draw ratio should be greater than 5.

The mesophase pitch-based tape of the invention can have novel orientation with graphite basal planes parallel to the major surface of the tape. This is beneficial to the development of extended graphitic plane structure. The tape may have two-dimensional graphitic properties due to the extended layer structure.

Preferably the mesophase pitch-based tape comprises a flat layer transverse texture.

Preferably the mesophase pitch-based tape comprises graphite basal planes parallel to the major surface of the tape.

In a preferred embodiment, the mesophase pitch based tape of the invention has an extended planar graphitic structure.

In a preferred embodiment, the tape is wound to make pipes or bars.

In a preferred embodiment, the tape is laminated with one or more ceramic materials as interlayers to give oxidation resistance at high temperatures.

In a preferred embodiment, the tape is formed into a honeycomb structure.

In a preferred embodiment, the tape or sheet of flat-layer transverse texture is laminated with fibre, ribbon, tape or sheet of line-origin transverse texture or any other material to control the thermomechanical properties, transport properties and resistance to oxidation.

In a preferred embodiment, the mesophase pitch-based tape is mixed with stabilised tapes from oxidation resistant material [see for example: Lu *et al*, *Journal of Mater Sci*, **34**, 571-578, 1999] to produce oxidation resistant bulk carbon material.

Viewed from a yet further aspect the present invention provides a process for preparing bulk carbon material, said process comprising:
processing a mesophase pitch-based tape as hereinbefore defined.

The process advantageously comprises the additional step of carbonising to carbonised bulk material or graphitising to graphitised bulk material.

In a preferred embodiment of the process of the invention, the processing step comprises: laminating or pressing the mesophase pitch-based tape.

Pressing is preferred and may be conducted at a carefully chosen pressures for a suitable length of time. By controlling the pressure used during pressing, it is possible to produce a range of bulk carbon materials with different thermal and mechanical properties. Typically pressing may be carried out a pressure of about 15-35MPa at

an elevated temperature (*eg* about 400°C) for an extended period of time (*eg* about 2 hours).

Preferably, the mesophase pitch-based tapes are stabilised (*eg* oxidatively stabilised) prior to pressing.

The process of the invention produces a high density bulk carbon material without any need for liquid phase impregnation or vapour phase infiltration.

Viewed from a further aspect the present invention provides a bulk carbon material obtainable by processing a mesophase pitch-based tape as hereinbefore defined.

In accordance with the invention, the highly oriented mesophase pitch-based graphite (HOMG) tapes and the bulk HOMG carbon materials have superior properties due to the two-dimensional extensive planar graphitic structure of the tapes and higher density of the final bulk product. Due to the high degree of orientation of the mesophase pitch-based tape, the bulk carbon (*eg* graphite material) is expected to have excellent transport properties.

The bulk carbon materials of the invention can be utilised in the aerospace, nuclear, metallurgical, chemical, mechanical, electronic and electrical industry. In particular, they are best suited in areas where heat generation limits efficiency or leads to component failure such as in high power electronic devices, high energy friction and braking systems, propulsion and energy generation equipment, as well as processing equipment operating in corrosive environments. The low production costs of the method and process of the invention will assist

widespread applications in these thermal management areas. Manufacturers will benefit from cheaper production cost and high performance products and user will benefit from improved devices with greater thermal properties and reliability.

The invention has been and will now be described in a non-limitative sense with reference to the Example and the accompanying Figures in which:

Figure 1: Schematic illustration of mesophase spheres coalescing to a larger sphere;
Figure 2: Schematic illustration of the transverse textures of various pitch-based carbon fibres (a) radial (b) onion skin (c) random (d) flat layer (e) line-origin ribbon fibre;
Figure 3: Relationship between electrical resistivity and thermal conductivity of mesophase pitch-based carbon fibres (Lavin *et al*, *Carbon*, 1993, **31**, 1001);
Figure 4: A flow diagram representing the route to graphite tape and its bulk material;
Figure 5: Texture of typical carbon tape; and
Figure 6: Schematic illustrations of bulk carbon material from tapes and circular fibres.

Example 1

An embodiment of the method of the invention for producing mesophase pitch-based tapes is outlined schematically in Figure 4. A commercial mesophase pitch ARA24 (100% anisotropic content, softening point 237°C) was used to prepare pitch tapes. The spinning precursor was formed into tape by a bench-scale melt-extrusion system at a temperature of 290°C through slit-shaped dies and drawing the extrudate.

The molten mesophase pitch was forced through the die by nitrogen gas. Three dies were used with rectangular slot dimensions of 0.14mm x 2.4mm, 0.1mm x 5 mm, and 0.1 mm x 8mm respectively. The depth of the slot is 0.5mm. Upon exiting the slot dies, the tapes were draw down and collected under ambient conditions on a variable speed winder. The draw ratio is defined as the thickness of the slot (*eg* 0.14 mm or 0.1 mm) divided by the thickness of the as-spun pitch tape prior to further treatment. The cross-sectional area of the tape was varied with the aspect ratio of the dies, shear rate and winding speed.

The mesophase pitch-based tape was produced using a die of aspect ratio 50 at a shear rate of $2338s^{-1}$ (spinning temperature 290°C, pressure 8 bar). The shear rate in the slot die is defined as the product of four times the volume flow rate (cm^3/sec) divided by the product of π times the cube of the hydraulic radius (cm) of the slot die. The hydraulic radius of the slot die is defined as the product of two times the cross-sectional area of the slot die (cm^2) divided by the perimeter of the slot die (cm).

The as-spun tape was oxidatively stabilised in air or oxygen at a temperature below 300°C producing a weight gain of 8-10% and then carbonised at 1000°C under nitrogen atmosphere. Some carbon tapes were further heat-treated at a higher temperature *eg* 2700°C.

The parallel sheet-like texture of carbon tapes is evident under the optical microscope and scanning electron microscope. This texture has been confirmed by results of X-ray diffraction (XRD) texture scan. The 1000°C heat-treated carbon tape is highly flexible with a transverse area

comparable to a combined transverse area of 100-200 conventional mesophase pitch-based carbon fibres. The carbon tape can be coiled into a sample vial with internal diameter of 20 mm. This carbon tape is also strong with a tensile strength of the order of 1GPa. After graphitisation at 2700°C, it shows unusual fracture behaviour with evidence of progressive failure and sliding of layers. Together with the highly irregular and fibrillar tensile fracture surface, this indicates that the tape has significant fracture toughness. This is believed to be due to the predominantly planar orientation of the structure combined with limited regions of locally misoriented structure that deflect the crack path and so hinder crack propagation. The ultimate strength was around 2GPa and the initial Young modulus is of the order of 500GPa.

The HOMG tape (HTT 2700°C) has an average electrical resistivity of 1.2$\mu\Omega$m equivalent to the value of K1100 that has been heat treated at a much higher temperature (>3000°C). This suggests that the HOMG tape can have a thermal conductivity value equivalent to K1100 if the inverse relationship between electrical resistivity and thermal conductivity for mesophase pitch-based carbon fibres is still valid for carbon tape (Fig. 3). The Raman spectrum and XRD profile demonstrate the highly graphitic structure of the HOMG tape.

Example 2

For the same mesophase pitch, using a die of aspect ratio 50 and a shear rate of *eg* 1961s^{-1}, 2017s^{-1}, 2178s^{-1}, 2599s^{-1}, 2684s^{-1}, 3150s^{-1}, 3273s^{-1}, 3363s^{-1} or 3830s^{-1}, tapes in which

the planar molecules arrange predominantly parallel to the major tape surface were produced.

Example 3

For the same mesophase pitch, using a die of aspect ratio 50, and a shear rate in the die of *eg* $5405s^{-1}$, $5463s^{-1}$, $8053s^{-1}$, $8828s^{-1}$, $8881s^{-1}$, $9126s^{-1}$, $9864s^{-1}$, $10953s^{-1}$, $11084s^{-1}$ or $32921s^{-1}$, tapes in which the planar molecules arrange predominantly perpendicular to the major tape surface were produced.

Example 4

For the same mesophase pitch, using a die of aspect ratio 80 and a shear rate of *eg* $1758s^{-1}$, $2688s^{-1}$, $3189s^{-1}$, $4828s^{-1}$, tapes in which the planar molecules arrange mainly parallel to the major tape surface were produced.

Example 5

For the same mesophase pitch, using a die of aspect ratio 80 and a shear rate of *eg* $6617s^{-1}$, $6991s^{-1}$ or $12585s^{-1}$, tapes in which the planar molecules arrange mainly perpendicular to the major tape surface were produced.

Example 6

Mesophase pitch was melt extruded from a rectangular die with an aspect ratio of 50 and continuously wound on to carbon felt which was fastened on a roller. The as-spun tapes were oxidatively stabilised and then cut into desired length. The tapes were loaded into a rectangular mould along

one direction and compacted under hot press with a ram pressure of 5-10 ton at a temperature of 400°C for 2 hours (see Fig. 6). These tapes softened under the effect of pressure and temperature and fuse together. However, the preferred orientation induced during extrusion and winding was retained. The bulk material was removed from the mould and heat treated under inert atmosphere to convert it into bulk carbon material.

For comparison, a circular fibre was used to make a similar bulk material. A schematic diagram of the various materials is shown in Figure 6. After carbonisation, the bulk carbon material from circular fibres cracked into a few pieces. However the bulk carbon material from a tape of the invention maintained integrity with no obvious cracks developed on the surfaces. This is attributable to the circular fibre structural constraints which inhibit shrinkage while the parallel nature of the layer planes in the tapes allows shrinkage and dissipation of such stresses.

The advantage of pressing stabilised tapes into desired shape is that the size of bulk materials is not limited by the subsequent stabilisation process as in Amoco's method. Additionally the tapes may be pressed at higher pressure to achieve higher bulk density of the order of 1.8 Mgm^{-3}. For example, after carbonisation at 1000°C, the bulk carbon material has an apparent density of the order of 1.9 Mgm^{-3} and the tapes are closely bonded together with little inter-tape porosity. The bulk carbon material has preferred orientation of layer structure parallel to the main bulk carbon surface. The pressure used for formation of the bulk materials must be carefully controlled so as not to destroy the individual tape to ensure high strength of the bulk

material. The bulk carbon materials obtained from tapes have higher density than those from circular fibres due to the lower porosity. This leads to a self-reinforced carbon material with two-dimensional ultra-high thermal conductivity at considerably reduced production cost.

CLAIMS

1. A method for preparing mesophase pitch-based tape comprising:

extruding mesophase pitch through a slot-shaped die with an aspect ratio of 10 or more and drawing at a draw ratio greater than 5.

2. A method as claimed in claim 1 comprising: stabilising the mesophase pitch-based tape.

3. A method as claimed in claim 1 or 2 comprising: oxidatively stabilising the mesophase pitch-based tape.

4. A method as claimed in any preceding claim wherein the planar molecules arrange mainly parallel to the major surface of the mesophase pitch-based tape.

5. A method as claimed in any of claims 1 to 3 wherein the planar molecules arrange mainly perpendicular to the major surface of the mesophase pitch-based tape.

6. A method as claimed in any preceding claim wherein the mesophase pitch based tape is subjected to an elevated temperature.

7. A method as claimed in any preceding claim wherein the aspect ratio of the die is 20 or more, particularly preferably 30 or more, more preferably 40 or more, more especially preferably about 50 or more, even more especially preferably 60 or more, yet even more especially preferably 70 or more.

8. A method as claimed in any preceding claim further comprising the step of carbonisation or graphitisation.

9. A method as claimed in any preceding claim wherein the shear rate in the die is $1000s^{-1}$ or more.

10. A method as claimed in claim 9 wherein the shear rate in the die is in the range 1000 to $33000s^{-1}$.

11. A method as claimed in either of claims 9 or 10 wherein the shear rate in the die is in the range 1000 to $5000s^{-1}$.

12. A method as claimed in any of claims 1 to 10 wherein the shear rate in the die is in the range 5000 to $33000s^{-1}$.

13. A method as claimed in claim 9 wherein the die has an aspect ratio of about 50 and the shear rate is in the range 5400 to $11100s^{-1}$.

14. A method as claimed in claim 9 wherein the die has an aspect ratio of about 50 and the shear rate is in the range 1900 to $4000s^{-1}$

15. A method as claimed in claim 9 wherein the die has an aspect ratio of about 80 and the shear rate is in the range 1700 to $4900s^{-1}$.

16. A method as claimed in claim 9 wherein the die has an aspect ratio of about 80 and the shear rate is in the range 6600 to $12600s^{-1}$.

17. A method as claimed in any preceding claim wherein the draw ratio is greater than 10.

18. A method as claimed in any preceding claim wherein the tape is of flat-layer transverse texture, said method further comprising: laminating the tape with a material capable of controlling the thermomechanical properties, transport properties or resistace to oxidation of the tape.

19. A method as claimed in claim 18 wherein the material is selected from the group consisting of fibre, ribbon, tape and sheet of line-origin transverse texture.

20. A mesophase pitch-based tape obtainable from a method as defined in any one of claims 1 to 19.

21. A mesophase pitch-based tape as claimed in claim 20 having a cross-sectional area of $500x10(\mu m)^2$ and exhibiting a tensile strength of about 1GPa.

22. A mesophase pitch-based tape as claimed in claim 20 heat-treated to 2700°C and having a cross-sectional area of about $8000(\mu m)^2$, wherein said tape exhibits an electrical resistivity of about $1.2\mu\Omega m$.

23. A mesophase pitch-based tape as claimed in any of claims 20 to 22 comprising a flat layer transverse texture.

24. A mesophase pitch-based tape as claimed in any of claims 20 to 23 comprising graphite basal planes parallel to the major surface of the tape.

25. A mesophase pitch-based tape as claimed in any of claims 20 to 24 comprising an extended graphitic plane structure.

26. A process for preparing a bulk carbon material comprising: processing mesophase pitch-based tape as defined in any of claims 20 to 25.

27. A process as claimed in claim 26 wherein processing comprises: laminating or pressing the tape.

28. A process as claimed in claim 26 or 27 wherein processing comprises: pressing the tape.

29. A process as claimed in any of claims 26 to 28 wherein the mesophase pitch-based tape is stabilised prior to processing.

30. A process as claimed in any of claims 26 to 29 comprising carbonising or graphitising the material after processing.

31. A bulk carbon material obtainable by conducting a process as defined in any of claims 26 to 30.

32. Use of a mesophase pitch-based tape as defined in any of claims 20 to 25 in the manufacture of polymer matrix composites, carbon matrix composites or metal matrix composites.

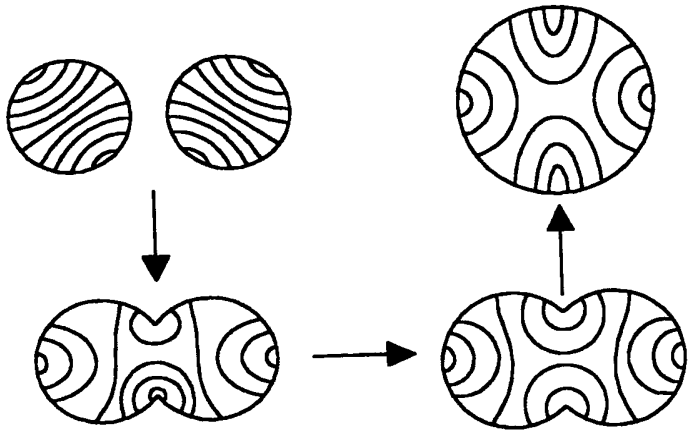

FIG. 1

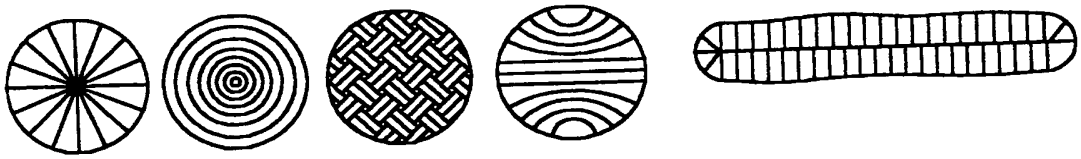

FIG. 2

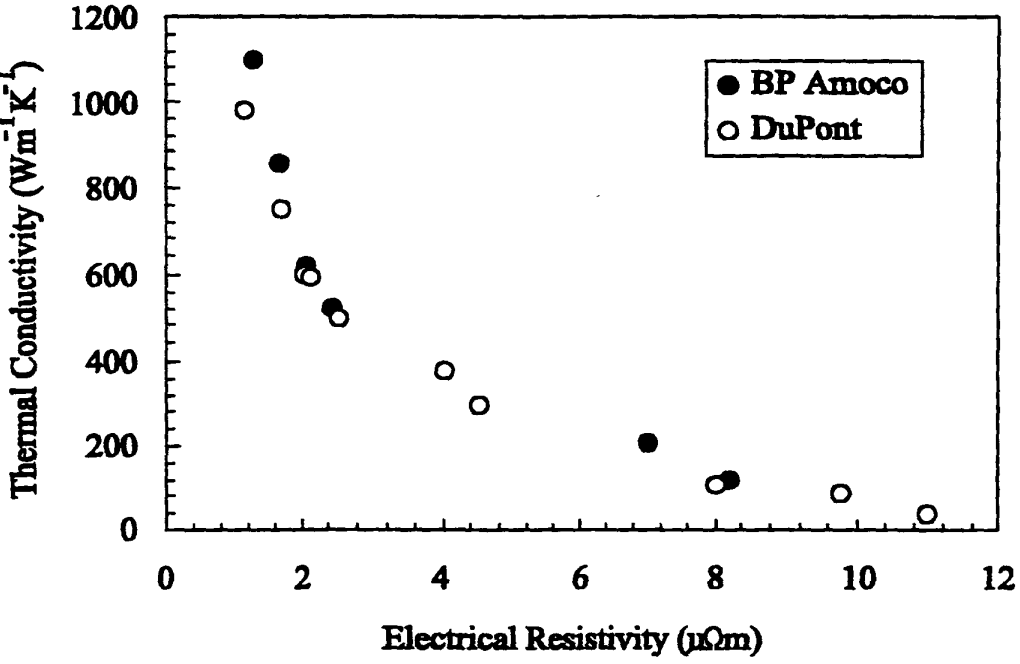
1200
1000
800
600
400
200
0
Thermal Conductivity ($Wm^{-1}K^{-1}$)
0
2
4
6
8
10
12
Electrical Resistivity (μΩm)
BP Amoco
DuPont

FIG. 3

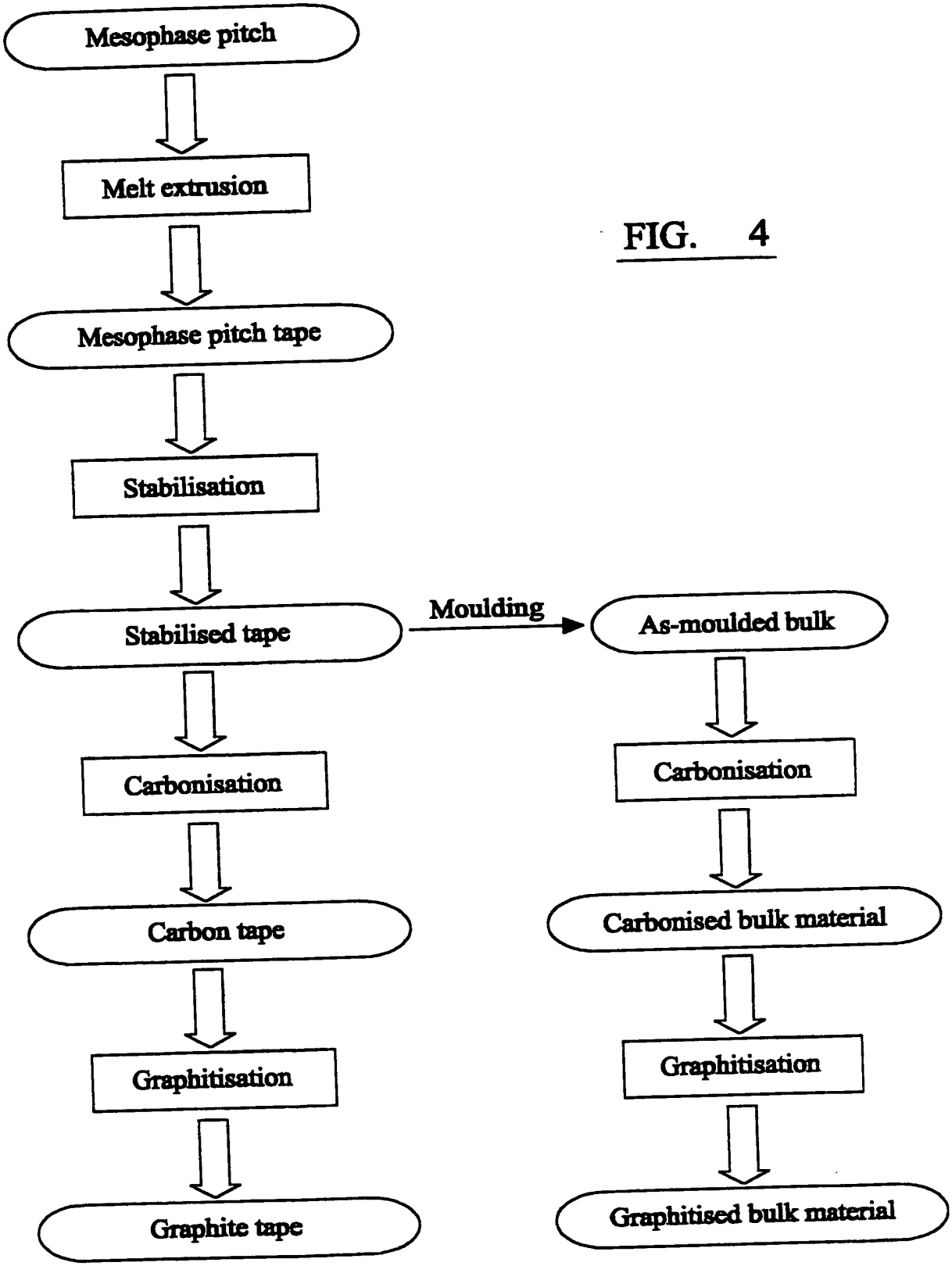
Mesophase pitch
Melt extrusion
Mesophase pitch tape
Stabilisation
Stabilised tape
Moulding
As-moulded bulk
Carbonisation
Carbon tape
Carbonisation
Carbonised bulk material
Graphitisation
Graphite tape
Graphitisation
Graphitised bulk material

FIG. 4

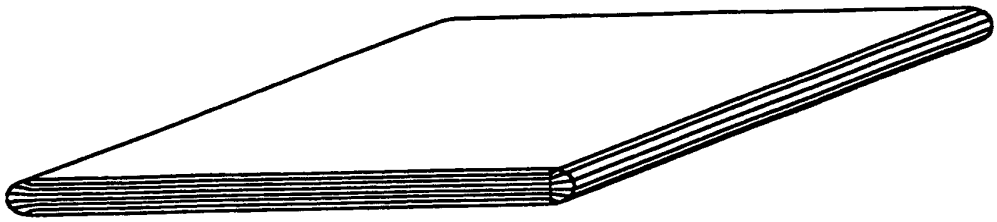

FIG. 5

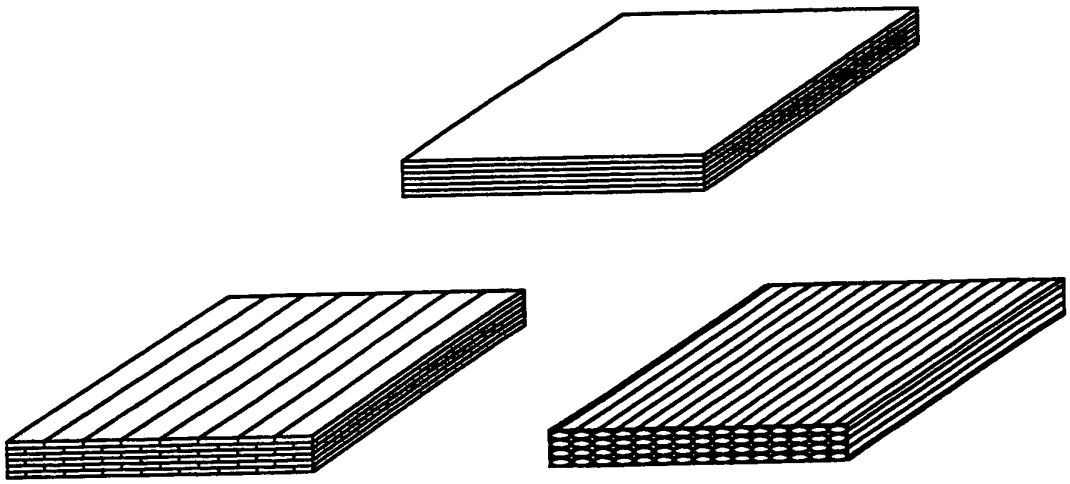

FIG. 6

INTERNATIONAL SEARCH REPORT

Interna il Application No
PCT/GB 00/02363

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 D01F9/145 D01F9/15 D01F9/155 D01D5/253

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 D01F D01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
CHEM ABS Data, EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DATABASE CHEMABS 'Online! CHEMICAL ABSTRACTS SERVICE, COLUMBUS, OHIO, US; HARAGUCHI, KAZUTOSHI ET AL: "Ribbonlike carbon fiber manufacture" retrieved from STN Database accession no. 107:60580 XP002149969 abstract & JP 62 078220 A (OSAKA GAS CO., LTD., JAPAN;DAINIPPON INK AND CHEMICALS, INC.) 10 April 1987 (1987-04-10) ---	1-3,6-8, 17,20,32
A	EP 0 463 170 A (OSAKA GAS CO LTD) 2 January 1992 (1992-01-02) the whole document ---	1-32
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 October 2000	27/10/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Tarrida Torrell, J

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INTERNATIONAL SEARCH REPORT

Interna al Application No
PCT/GB 00/02363

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 011, no. 139 (C-420), 7 May 1987 (1987-05-07) & JP 61 275426 A (MITSUI COKES KOGYO KK), 5 December 1986 (1986-12-05) abstract	1-17, 20-25,32
A	DAUCHE F M ET AL: "Ribbon-Shaped Carbon Fibers from Supercritically Extracted Mesophase Pitches" CARBON,US,ELSEVIER SCIENCE PUBLISHING, NEW YORK, NY, vol. 36, no. 7-8, 1998, pages 1238-1240, XP004124201 ISSN: 0008-6223 the whole document	1-17, 20-25,32
A	ROBINSON K E ET AL: "Microstructure and texture of pitch-based ribbon fibers for thermal management" CARBON,US,ELSEVIER SCIENCE PUBLISHING, NEW YORK, NY, vol. 34, no. 1, 1996, pages 13-36, XP004022389 ISSN: 0008-6223 the whole document	1-17, 20-25,32

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Interna al Application No
PCT/GB 00/02363

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 62078220 A	10-04-1987	NONE	
EP 0463170 A	02-01-1992	DE 69027850 D	22-08-1996
		DE 69027850 T	28-11-1996
		US 5326510 A	05-07-1994
		JP 4211933 A	03-08-1992
		WO 9110557 A	25-07-1991
JP 61275426 A	05-12-1986	NONE	

PATENT COOPERATION TREA

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
GS/P61575WO		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/GB 00/ 02363	03/07/2000	01/07/1999
Applicant		
UNIVERSITY OF LEEDS		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 03 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. ---

   [ ] None of the figures.

   [ ] as suggested by the applicant.

   [ ] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/02363

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 D01F9/145 D01F9/15 D01F9/155 D01D5/253

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 . D01F D01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
CHEM ABS Data, EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	EP 0 463 170 A (OSAKA GAS CO LTD) 2 January 1992 (1992-01-02) the whole document ---	1-32
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 October 2000	27/10/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Tarrida Torrell, J

1

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 011, no. 139 (C-420), 7 May 1987 (1987-05-07) & JP 61 275426 A (MITSUI COKES KOGYO KK), 5 December 1986 (1986-12-05) abstract	1-17, 20-25,32
A	DAUCHE F M ET AL: "Ribbon-Shaped Carbon Fibers from Supercritically Extracted Mesophase Pitches" CARBON,US,ELSEVIER SCIENCE PUBLISHING, NEW YORK, NY, vol. 36, no. 7-8, 1998, pages 1238-1240, XP004124201 ISSN: 0008-6223 the whole document	1-17, 20-25,32
A	ROBINSON K E ET AL: "Microstructure and texture of pitch-based ribbon fibers for thermal management" CARBON,US,ELSEVIER SCIENCE PUBLISHING, NEW YORK, NY, vol. 34, no. 1, 1996, pages 13-36, XP004022389 ISSN: 0008-6223 the whole document	1-17, 20-25,32

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/02363

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 62078220 A	10-04-1987	NONE	
EP 0463170 A	02-01-1992	DE 69027850 D	22-08-1996
		DE 69027850 T	28-11-1996
		US 5326510 A	05-07-1994
		JP 4211933 A	03-08-1992
		WO 9110557 A	25-07-1991
JP 61275426 A	05-12-1986	NONE	

XP-002149969

P.D. 1987
p. 1 = (1)

(C) FILE CAPLUS
STN CA Caesar accession number : 1527
AN - 1987:460580 CAPLUS
DN - 107:60580
TI - Ribbonlike carbon fiber manufacture
IN - Haraguchi, Kazutoshi; Tanigawa, Eiji; Nukina, Kenji; Minami, Hiroaki; Maeda, Toyohiro
PA - Osaka Gas Co., Ltd., Japan; Dainippon Ink and Chemicals, Inc.
SO - Jpn. Kokai Tokkyo Koho, 7 pp.
CODEN: JKXXAF
DT - Patent
LA - Japanese
FAN.CNT 1

PATENT NO.	KIND	DATE	APPLICATION NO.	DATE
PN - JP62078220	A	19870410	JP 1985-219761	19851002 <--

AB - The title carbon fibers are prepd. by melt spinning optically anisotropic pitch through a spinneret having slitted holes with ratio of its width to its length 2-300 at draft ratio 10-3000, oxidizing the fibers at 280-440.degree., and finally carbonizing them. Thus, an optically anisotropic pitch with degree of anisotropicity 98.5 vol. %, quinoline-insol. fraction 33%, and softening temp. 315.degree. was prepd., spun through a spinneret with slitted holes with width 3.0 mm and length 0.1 mm at draft ratio 800. The spun fibers were then oxidized in air at 310.degree. and carbonized 10 min at 1200.degree. under N to give ribbonlike carbon fibers with tensile strength 272 kg/mm2, vs. 124 kg/mm2 for carbon fibers obtained from pitch with degree of anisotropicity 60.0 vol. %.

INTERNATIONAL SEARCH REPORT

Interna il Application No
PCT/GB 00/02363

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 D01F9/145 D01F9/15 D01F9/155 D01D5/253

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 D01F D01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
CHEM ABS Data, EPO-Internal, PAJ, WPI Data

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A	EP 0 463 170 A (OSAKA GAS CO LTD) 2 January 1992 (1992-01-02) the whole document ---	1-32
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 October 2000	27/10/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Tarrida Torrell, J

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INTERNATIONAL SEARCH REPORT

Interna al Application No
PCT/GB 00/02363

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 011, no. 139 (C-420), 7 May 1987 (1987-05-07) & JP 61 275426 A (MITSUI COKES KOGYO KK), 5 December 1986 (1986-12-05) abstract	1-17, 20-25,32
A	DAUCHE F M ET AL: "Ribbon-Shaped Carbon Fibers from Supercritically Extracted Mesophase Pitches" CARBON,US,ELSEVIER SCIENCE PUBLISHING, NEW YORK, NY, vol. 36, no. 7-8, 1998, pages 1238-1240, XP004124201 ISSN: 0008-6223 the whole document	1-17, 20-25,32
A	ROBINSON K E ET AL: "Microstructure and texture of pitch-based ribbon fibers for thermal management" CARBON,US,ELSEVIER SCIENCE PUBLISHING, NEW YORK, NY, vol. 34, no. 1, 1996, pages 13-36, XP004022389 ISSN: 0008-6223 the whole document	1-17, 20-25,32

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Interna il Application No
PCT/GB 00/02363

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 62078220 A	10-04-1987	NONE	
EP 0463170 A	02-01-1992	DE 69027850 D	22-08-1996
		DE 69027850 T	28-11-1996
		US 5326510 A	05-07-1994
		JP 4211933 A	03-08-1992
		WO 9110557 A	25-07-1991
JP 61275426 A	05-12-1986	NONE	

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE
in its capacity as elected Office

Date of mailing (day/month/year) 15 March 2001 (15.03.01)	
International application No. PCT/GB00/02363	**Applicant's or agent's file reference** GS/P61575WO
International filing date (day/month/year) 03 July 2000 (03.07.00)	**Priority date** (day/month/year) 01 July 1999 (01.07.99)
Applicant Appleyard, Steven, Philips et al	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:
   23 January 2001 (23.01.01)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was
   [ ] was not
   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer Juan Cruz
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

GB0002363

Form PCT/IB/331 (July 1992)

PATENT COOPERATION TREATY

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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
GS/P61575WO		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/02363	03/07/2000	01/07/1999
International Patent Classification (IPC) or national classification and IPC		
D01F9/145		
Applicant		
UNIVERSITY OF LEEDS		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 3 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
23/01/2001	25.09.2001
Name and mailing address of the international preliminary examining authority:	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Lux, R Telephone No. +49 89 2399 8593

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/02363

I. Basis of th rep rt

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

1-22 as originally filed

Claims, No.:

1-24 as received on 25/06/2001 with letter of 25/06/2001

Drawings, sheets:

1/4-4/4 filed with the demand

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

Re Item V

Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

There is novelty and inventive step of the **method** defined in the amended set of claims over D1 (abstract of JP-A-62078220) and D2 (EP-A-0 463 170) since the methods defined in present claims 1 and 18, including the specific combination of aspect ratio **and** shear rate, are not suggested in the available prior art.

D1 discloses the melt spinning of "optically anisotropic" pitch (anisotropic=mesophase) through slitted holes with an aspect ratio of 2-300 and at a draft ratio of from 10-3000, whereas D2 shows the following parameters:
Example 1: aspect ratio = 100; shear rate = 24 961 s^{-1}
Example 1: aspect ratio = 100; shear rate = 12 480 s^{-1}
Example 1: aspect ratio = 33; shear rate = 41 390 s^{-1}

By carfully controlling the shear rate and draw ratio, mesohase pitch-based tapes can be obtained which have the planar moleculaes predominantly arranged parallel to the major tape surface thereby leading to surprising advantages such as low electrical resistivity, high thermal conductivity, and high tensile strength.

In contrast, the novelty and inventive step of present claims 13 **and** 23 being drafted in form of a "product-by-process" claim cannot be acknowledged.
Claim 13 now includes the additional feature that the tape comprises "graphite basal planes parallel to the major surface of the tape". This amendment does not necessarily represent a novelty-establishing feature. Although, this feature is not disclosed explicitly in either D1 or D2, it may be assumed with reasonable expectation (cf. process features disclosed in the cited prior art) that the products of D1 and/or D2 may also satisfy this additional requirement, ie that all product features are inherently disclosed in said patents.
Moreover, it should be born in mind that a new process does not necessarily lead to a new product. The product per se should be new and inventive over the cited prior art, ie a product claim should include at least one distinguishing and inventive feature so as to satisfy the requirements of Art. 33 (2)/(3) PCT.

R It m VII
Certain defects in the international application

The description has not been adapted to the language of the new set of claims.

Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the document D1 is not mentioned in the description, nor is this document identified therein.
A document reflecting the prior art described on page 3 last paragraph, is not identified in the description either.

Re Item VIII
Certain observations on the international application

Taking into account the explanations given in the letter of 25.06.2001 (cf. page 2), it appears that an essential feature is not defined in claim 1. In said letter of reply it is stated twice that the "surprising advantages" are achieved (solution of the problem posed) by a method including an additional "**heat treatment**" of the tape.
Since independent claims 1 and 18 do not contain this feature they do not meet the requirement following from Article 6 PCT taken in combination with Rule 6.3 (b) PCT that any independent claim must contain **all** the technical features essential to the definition of the invention.

Further, contrary to the requirements of Art. 6 PCT claim 18 is not clear since the processing steps are not defined clearly (ie are not defined at all). This claim includes a reference to claims 13-17, however, theses claims do not include any processing step either.

CLAIMS

1. A method for preparing mesophase pitch-based tape comprising:

extruding mesophase pitch through a slot-shaped die with an aspect ratio of 10 or more and drawing at a draw ratio greater than 5.

2. A method as claimed in claim 1 comprising: stabilising the mesophase pitch-based tape.

3. A method as claimed in claim 1 or 2 comprising: oxidatively stabilising the mesophase pitch-based tape.

4. A method as claimed in any preceding claim wherein the planar molecules arrange mainly parallel to the major surface of the mesophase pitch-based tape.

5. A method as claimed in any of claims 1 to 3 wherein the planar molecules arrange mainly perpendicular to the major surface of the mesophase pitch-based tape.

6. A method as claimed in any preceding claim wherein the mesophase pitch based tape is subjected to an elevated temperature.

7. A method as claimed in any preceding claim wherein the aspect ratio of the die is 20 or more, particularly preferably 30 or more, more preferably 40 or more, more especially preferably about 50 or more, even more especially preferably 60 or more, yet even more especially preferably 70 or more.

Replaced by article 34

8. A method as claimed in any preceding claim further comprising the step of carbonisation or graphitisation.

9. A method as claimed in any preceding claim wherein the shear rate in the die is $1000s^{-1}$ or more.

10. A method as claimed in claim 9 wherein the shear rate in the die is in the range 1000 to $33000s^{-1}$.

11. A method as claimed in either of claims 9 or 10 wherein the shear rate in the die is in the range 1000 to $5000s^{-1}$.

12. A method as claimed in any of claims 1 to 10 wherein the shear rate in the die is in the range 5000 to $33000s^{-1}$.

13. A method as claimed in claim 9 wherein the die has an aspect ratio of about 50 and the shear rate is in the range 5400 to $11100s^{-1}$.

14. A method as claimed in claim 9 wherein the die has an aspect ratio of about 50 and the shear rate is in the range 1900 to $4000s^{-1}$

15. A method as claimed in claim 9 wherein the die has an aspect ratio of about 80 and the shear rate is in the range 1700 to $4900s^{-1}$.

16. A method as claimed in claim 9 wherein the die has an aspect ratio of about 80 and the shear rate is in the range 6600 to $12600s^{-1}$.

17. A method as claimed in any preceding claim wherein the draw ratio is greater than 10.

18. A method as claimed in any preceding claim wherein the tape is of flat-layer transverse texture, said method further comprising: laminating the tape with a material capable of controlling the thermomechanical properties, transport properties or resistace to oxidation of the tape.

19. A method as claimed in claim 18 wherein the material is selected from the group consisting of fibre, ribbon, tape and sheet of line-origin transverse texture.

20. A mesophase pitch-based tape obtainable from a method as defined in any one of claims 1 to 19.

21. A mesophase pitch-based tape as claimed in claim 20 having a cross-sectional area of $500 \times 10 (\mu m)^2$ and exhibiting a tensile strength of about 1GPa.

22. A mesophase pitch-based tape as claimed in claim 20 heat-treated to 2700°C and having a cross-sectional area of about $8000 (\mu m)^2$, wherein said tape exhibits an electrical resistivity of about $1.2 \mu\Omega m$.

23. A mesophase pitch-based tape as claimed in any of claims 20 to 22 comprising a flat layer transverse texture.

24. A mesophase pitch-based tape as claimed in any of claims 20 to 23 comprising graphite basal planes parallel to the major surface of the tape.

25. A mesophase pitch-based tape as claimed in any of claims 20 to 24 comprising an extended graphitic plane structure.

26. A process for preparing a bulk carbon material comprising: processing mesophase pitch-based tape as defined in any of claims 20 to 25.

27. A process as claimed in claim 26 wherein processing comprises: laminating or pressing the tape.

28. A process as claimed in claim 26 or 27 wherein processing comprises: pressing the tape.

29. A process as claimed in any of claims 26 to 28 wherein the mesophase pitch-based tape is stabilised prior to processing.

30. A process as claimed in any of claims 26 to 29 comprising carbonising or graphitising the material after processing.

31. A bulk carbon material obtainable by conducting a process as defined in any of claims 26 to 30.

32. Use of a mesophase pitch-based tape as defined in any of claims 20 to 25 in the manufacture of polymer matrix composites, carbon matrix composites or metal matrix composites.

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

STUTTARD, Garry Philip
URQUHART-DYKES & LORD
Tower House
Merrion Way
Leeds LS2 8PA
GRANDE BRETAGNE

UDL LEEDS
27 SEP 2001

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT
(PCT Rule 71.1)

	Date of mailing *(day/month/year)* 25.09.2001
Applicant's or agent's file reference GS/P61575WO	**IMPORTANT NOTIFICATION**

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/02363	03/07/2000	01/07/1999

Applicant
UNIVERSITY OF LEEDS

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Le Bolloch, C Tel.+49 89 2399-8091

Form PCT/IPEA/416 (July 1992)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
GS/P61575WO		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/02363	03/07/2000	01/07/1999
International Patent Classification (IPC) or national classification and IPC		
D01F9/145		
Applicant		
UNIVERSITY OF LEEDS		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 3 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
23/01/2001	25.09.2001
Name and mailing address of the international preliminary examining authority:	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Lux, R Telephone No. +49 89 2399 8593

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/02363

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

1-22 as originally filed

Claims, No.:

1-24 as received on 25/06/2001 with letter of 25/06/2001

Drawings, sheets:

1/4-4/4 filed with the demand

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	
	No:	Claims	1-24
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-24
Industrial applicability (IA)	Yes:	Claims	1-24
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

R Item V

Reasoned statement under Rule 66.2(a)(ii) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

There is novelty and inventive step of the **method** defined in the amended set of claims over D1 (abstract of JP-A-62078220) and D2 (EP-A-0 463 170) since the methods defined in present claims 1 and 18, including the specific combination of aspect ratio **and** shear rate, are not suggested in the available prior art.

D1 discloses the melt spinning of "optically anisotropic" pitch (anisotropic=mesophase) through slitted holes with an aspect ratio of 2-300 and at a draft ratio of from 10-3000, whereas D2 shows the following parameters:
Example 1: aspect ratio = 100; shear rate = 24 961 s^{-1}
Example 1: aspect ratio = 100; shear rate = 12 480 s^{-1}
Example 1: aspect ratio = 33; shear rate = 41 390 s^{-1}

By carfully controlling the shear rate and draw ratio, mesohase pitch-based tapes can be obtained which have the planar moleculaes predominantly arranged parallel to the major tape surface thereby leading to surprising advantages such as low electrical resistivity, high thermal conductivity, and high tensile strength.

In contrast, the novelty and inventive step of present claims 13 **and** 23 being drafted in form of a "product-by-process" claim cannot be acknowledged.
Claim 13 now includes the additional feature that the tape comprises "graphite basal planes parallel to the major surface of the tape". This amendment does not necessarily represent a novelty-establishing feature. Although, this feature is not disclosed explicitly in either D1 or D2, it may be assumed with reasonable expectation (cf. process features disclosed in the cited prior art) that the products of D1 and/or D2 may also satisfy this additional requirement, ie that all product features are inherently disclosed in said patents.
Moreover, it should be born in mind that a new process does not necessarily lead to a new product. The product per se should be new and inventive over the cited prior art, ie a product claim should include at least one distinguishing and inventive feature so as to satisfy the requirements of Art. 33 (2)/(3) PCT.

R It m VII
Certain defects in the international application

The description has not been adapted to the language of the new set of claims.

Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the document D1 is not mentioned in the description, nor is this document identified therein.
A document reflecting the prior art described on page 3 last paragraph, is not identified in the description either.

Re Item VIII
Certain observations on the international application

Taking into account the explanations given in the letter of 25.06.2001 (cf. page 2), it appears that an essential feature is not defined in claim 1. In said letter of reply it is stated twice that the "surprising advantages" are achieved (solution of the problem posed) by a method including an additional "**heat treatment**" of the tape.
Since independent claims 1 and 18 do not contain this feature they do not meet the requirement following from Article 6 PCT taken in combination with Rule 6.3 (b) PCT that any independent claim must contain **all** the technical features essential to the definition of the invention.

Further, contrary to the requirements of Art. 6 PCT claim 18 is not clear since the processing steps are not defined clearly (ie are not defined at all). This claim includes a reference to claims 13-17, however, theses claims do not include any processing step either.

CLAIMS

1. A method for preparing mesophase pitch-based tape comprising:

extruding mesophase pitch through a slot-shaped die with an aspect ratio of 50 or more and drawing at a draw ratio greater than 5, wherein the shear rate in the die is in the range 1000 to 5000s^{-1}.

2. A method as claimed in claim 1 comprising: stabilising the mesophase pitch-based tape.

3. A method as claimed in claim 1 or 2 comprising: oxidatively stabilising the mesophase pitch-based tape.

4. A method as claimed in any preceding claim wherein the planar molecules arrange mainly parallel to the major surface of the mesophase pitch-based tape.

5. A method as claimed in any preceding claim wherein the mesophase pitch based tape is subjected to an elevated temperature.

6. A method as claimed in any preceding claim wherein the aspect ratio of the die is 60 or more, preferably 70 or more.

7. A method as claimed in any preceding claim further comprising the step of carbonisation or graphitisation.

8. A method as claimed in claim 1 wherein the die has an aspect ratio of about 50 and the shear rate is in the range 1900 to 4000s^{-1}

9. A method as claimed in claim 1 wherein the die has an aspect ratio of about 80 and the shear rate is in the range 1700 to 4900s^{-1}.

10. A method as claimed in any preceding claim wherein the draw ratio is greater than 10.

11. A method as claimed in any preceding claim wherein the tape is of flat-layer transverse texture, said method further comprising: laminating the tape with a material capable of controlling the thermomechanical properties, transport properties or resistace to oxidation of the tape.

12. A method as claimed in claim 11 wherein the material is selected from the group consisting of fibre, ribbon, tape and sheet of line-origin transverse texture.

13. A mesophase pitch-based tape obtainable from a method as defined in any one of claims 1 to 12 comprising graphite basal planes parallel to the major surface of the tape.

14. A mesophase pitch-based tape as claimed in claim 13 having a cross-sectional area of 500x10$(\mu m)^2$ and exhibiting a tensile strength of about 1GPa.

15. A mesophase pitch-based tape as claimed in claim 13 heat-treated to 2700°C and having a cross-sectional area of about 8000$(\mu m)^2$, wherein said tape exhibits an electrical resistivity of about 1.2$\mu\Omega m$.

16. A mesophase pitch-based tape as claimed in any of claims 13 to 15 comprising a flat layer transverse texture.

17. A mesophase pitch-based tape as claimed in any of claims 13 to 16 comprising an extended graphitic plane structure.

18. A process for preparing a bulk carbon material comprising: processing mesophase pitch-based tape as defined in any of claims 13 to 17.

19. A process as claimed in claim 18 wherein processing comprises: laminating or pressing the tape.

20. A process as claimed in claim 18 or 19 wherein processing comprises: pressing the tape.

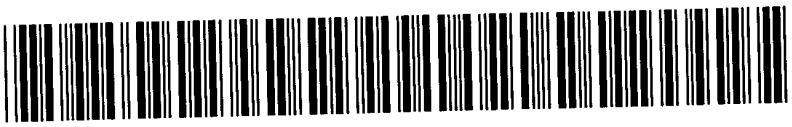
21. A process as claimed in any of claims 18 to 20 wherein the mesophase pitch-based tape is stabilised prior to processing.

22. A process as claimed in any of claims 18 to 21 comprising carbonising or graphitising the material after processing.

23. A bulk carbon material obtainable by conducting a process as defined in any of claims 18 to 22.

24. Use of a mesophase pitch-based tape as defined in any of claims 13 to 17 in the manufacture of polymer matrix composites, carbon matrix composites or metal matrix composites.

US 1001962504P1



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Team: OIPEProvisionFormalities
Dossier: 10019625

Legal Date: 03-12-2003

No.	Doccode	Number of pages
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8	PET.	2
9	OATH	5

Total number of pages: 35

Remarks:

Order of re-scan issued on .....